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Art. I.—*Phenomena of the Capillary Circulation.*

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The statements which I shall make from my own observation concerning the capillary circulation, are based upon examinations made from time to time during the past summer, nine of which have been carefully recorded. The recorded observations were made on the web of the frog, although I have made examinations of the various other parts where the circulation can be conveniently exhibited, to which I shall refer.

The microscope used was the large instrument of Nachet, and, unless otherwise stated, with a magnifying power of 165 diameters.

I shall first point out what I have found to be the most convenient methods of conducting examinations of the circulation in the frog, and then proceed to describe the various phenomena of the circulation as viewed by means of the microscope, and then draw my deductions from these observations.

The parts of the frog which I have subjected to examination, are the web of the foot, the tongue, the peritoneum, and the lungs. All parts but the peritoneum require to be examined by transmitted light, but, in examining the circulation in the latter situation, we are compelled to use reflected light.

It is exceedingly inconvenient to make observations while the frog has the power of motion, and in securing it to the frog-plate in a proper position, we are apt to interrupt or modify the circulation by constricting the vessels with the bands which we must use. Under these circumstances, we are not able to apply medicated solutions conveniently to the entire surface, and mechanical or chemical irritation of any part occasions struggles which greatly increase the difficulty of the experiment. By breaking up the medulla oblongata, or even the posterior part of the brain (for it is not easy to invariably reach the medulla without some practice), we are enabled to observe all the phenomena of the circulation with great facility, avoiding the necessity of forcibly retaining the frog in the desired position, with the consequent liability to constriction of the vessels and shifting of the field of observation. I shall hereafter refer to experiments of E. Brown Séquard, M. D., of Paris, and two of my recorded examinations, which show that observations of the circulation may be made with as much accuracy on a frog after the medulla has been destroyed, as though it had not been subjected to the operation. The operation may be performed by introducing a dissecting needle into the cranium, a line or two behind the eyes, passing it backwards and a little downwards to the articulation of the spine with the skull, and then thoroughly breaking up the medulla. The web of the foot may be examined in the following manner: We first break up the medulla oblongata in the manner just described, the frog will then remain perfectly motionless in any position. The web may be stretched over the opening in the frog-plate, and secured in position by means of pins; care being taken not to extend the web too forcibly, and to put no pins above the foot, but nearly at the extremities of the toes, as in either case the circulation may be disturbed. The part should then be moistened, and the lenses of the microscope protected from the evaporation by a glass cover, broken to fit between the toes.

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The entire surface of the frog should be moistened from time to time with cool water.

The magnifying power best adapted to such observations, is one of from 150 to 200 diameters.

In examining the tongue, we draw it out of the mouth, and stretch it so as to form a thin transparent film, by means of the forceps and pins. The circulation may be exhibited in the peritoneum by merely exposing that membrane and examining it, with a power of 60 or 70 diameters, by reflected light. The process of exhibiting the circulation in the lungs of the frog is much more complicated and difficult than either of the preceding experiments, but when successfully performed, it is one of the most beautiful and curious demonstrations in the whole range of microscopic science.

Dr. Robert Willis, in his edition of *Wagner's Physiology*, refers to the appearances of the pulmonary circulation in the water newt. He directs that the newt be strangled after an inspiration. "The abdomen is then to be laid open, and the entire animal, being held in the hands, is placed upon a glass plate as a *porte-objet*, and one of the lungs brought into the field of view." He observes, however, that the circulation lasts but a short time. The frog appears to me to be a much better subject for this experiment, and as I have never seen the process of showing the pulmonary circulation in this animal detailed in the books, I shall describe it with some minuteness as practised by Prof. John C. Dalton, of New York, and as repeated frequently by myself.

In undertaking it, a large sized frog should be selected. After having broken up the medulla oblongata, a ligature is to be placed around the larynx in the following manner: The mouth being widely opened, the larynx is seen just in front of the œsophagus. A ligature is now carried just under the mucous membrane by means of a small curved needle. This is effected by making four or five stitches, the needle being introduced at the point where it came out at each preceding stitch, so that the ligature shall smoothly encircle the larynx, and its extremities emerge at the same point. This being done, a small blowpipe is introduced into the windpipe, and the ligature held in readiness to be drawn tight by an assistant when required. The lungs must now be moderately distended and the ligature tightened, at the same time removing the blowpipe. If the side be now carefully opened the lung will protrude, and may be examined by transmitted light.

It is very much more difficult to exhibit the circulation in the lungs than in any other part. The chief difficulties to be encountered are the following: First, it is no easy matter to fix the ligature properly around the larynx; but when we have done this, if we distend the lungs too forcibly, they will either burst or the circulation will be greatly impeded; and if we do not distend them sufficiently, they will not protrude when the side is opened. There is also always some difficulty in introducing the blowpipe, and its delicate orifice is often occluded by the secretion of the part. When we succeed, however, in exhibiting the circulation in the lungs, the capillaries are seen encircling the air-cells, which are quite large in the frog. This is an extremely beautiful and interesting sight—but more as a scientific curiosity than as a field for useful investigation. It was observed by Dr. Willis, and confirmed by Wagner and Gluge, that the transparent plasma which we find occupying the space next to the walls of the capillaries, in most situations, while the blood-disks occupy the centre, constituting the still layer of Kirkes, is not observed in the capillaries of the lungs; in other words, the vessels are crowded to their very walls with corpuscles.

For this remarkable deviation from a general law they offer no explanation.

I have never observed this peculiarity, as my attention was not directed to it when examining the pulmonary circulation. Those who believe the heart is solely instrumental in propelling the blood through the capillaries would not be able to account for this phenomenon; but it seems to me it can be explained in the following manner: The blood circulating in the systemic capillaries nourishes the tissues by the liquor sanguinis, and thus the attractive vital force operates on this constituent. The plasma then is nearest the tissues and next the walls of the vessels; but the pulmonary capillaries are for the aeration of the blood, a process which is effected by the globules and not by the plasma—since the great mass of blood is not sent to the lungs for purposes of nutrition, but for aeration; hence, the *globules*, which here feel the force of attraction for oxygen, occupy the space next the walls of the vessels.

Taking the view which I do of the causes of the capillary circulation, this explanation is satisfactory.

Before proceeding to describe minutely the phenomena of the capillary circulation, we will briefly consider the anatomical structure of the capillaries and of the blood.

M. Robin recognizes three varieties of capillaries. The first variety is from $\frac{1}{3000}$ to $\frac{1}{830}$ of an inch in diameter, and is composed of a transparent homogeneous membrane, $\frac{1}{2500}$ of an inch in thickness, with nuclei, and sometimes nucleoli, projecting into the calibre of the vessel. The nuclei are oval, with their longest diameter in the direction of the vessel. These are embraced under the head of the "true capillaries" of Prof. Kölliker.

The second variety, M. Robin describes as having two coats: the membrane with the longitudinal nuclei of the first variety, and, investing it, a second membrane with transverse nuclei. The diameter of the second variety varies from $\frac{1}{830}$ to $\frac{1}{333}$ of an inch. This variety also probably comes under the head of the "true capillaries" as described by Kölliker, though he does not mention the second investing membrane.

The third variety, M. Robin calls venules and arterioles, Kölliker, venous and arterial transitionary vessels. Their diameter is from $\frac{1}{33}$ to $\frac{1}{17}$ of an inch, and they have added to the two coats of the second variety a third coat of areolar tissue. It seems to me most convenient and proper to consider the first two varieties of M. Robin, or the "true capillaries" of Prof. Kölliker, simply as capillaries (their tunic being a prolongation of the inner coat of the arteries), and the third variety of M. Robin as venules and arterioles. We may easily distinguish the arterioles from the venules, by noticing that the arterioles give off branches, while the venules receive them; that the arterioles diminish in size as we follow them in the direction of the current of blood, while the venules increase in size.

The blood consists of a transparent plasma holding two kinds of corpuscles in suspension, called the red and the white, or colorless. In the human subject the red corpuscles are disks like pieces of coin, but thinner in the centre than at the edges. They have no nuclei, though the difference in thickness causes the centre to appear dark when the edges are in focus. They are $\frac{1}{3500}$ of an inch in diameter. The white corpuscles are larger than the red, being $\frac{1}{2500}$ of an inch in diameter; they are globular, white, and granular. If water be applied to them they are rendered transparent, and we can distinguish a nucleus. They are much less numerous than the red corpuscles. In the frog, the red corpuscles are oval and large, with a central rounded nucleus. They are $\frac{1}{1000}$ of an inch in their long diameter. The white globules are smaller and proportionally more numerous than in man. The blood-disks in nearly all animals are red by reflected light, but of a pale amber colour by transmitted light.

Having given an abstract of the anatomy of the capillaries and of the blood, we are prepared to consider the phenomena of the circulation in these vessels.

In a paper communicated to the *Medical Examiner*, August, 1852, by E. Brown Séquard, M. D., of Paris, entitled "Experimental Researches applied to Physiology and Pathology," I find some very interesting observations on the effect, or more properly the absence of effect, on the capillary circulation, of the section of various nerves. This observer, with the assistance of Dr. Siebert, found, "after the section of all the nerves (the sympathetic and cerebro-spinal) in the legs of a number of frogs, that there was no appearance of trouble in the capillary circulation, either in one hour or three or four days after the division of the nerves." He concludes, from another experiment, that the nervous action (that of the sympathetic as well as the cerebro-spinal nerves) is not necessary for the change of colour of the blood in the capillaries. It is proved, by this experiment, that the capillary circulation is not immediately dependent, in any measure, on nervous influence.

A curious fact has been observed by Bernard, viz: that, after a section of the sympathetic in the neck, the corresponding side of the face, and more particularly the ear, becomes warmer and more sensitive than the other side. The bloodvessels appear more numerous than before, and are enlarged. Brown Séquard has repeated this experiment, and concludes that the increase of temperature and sensibility is due merely to passive dilatation of the vessels from paralysis of their coats and consequent congestion. I have myself seen the experiment performed by Prof. Dalton, of New York, and concur with him in the opinion that the increase in temperature and sensibility is rather due to an exaggeration of the nutrition of the parts: for specimens of blood drawn from the two ears have been compared, and there has been found a marked difference in their actual chemical composition.

These considerations are interesting in connection with animal heat, as produced by the molecular changes in the various tissues, and appear, also, to bear in some measure on the subject of the capillary circulation.

I shall hereafter take the ground that the capillary circulation is, in a great measure, dependent upon an attraction of a chemico-vital character between the tissues and the nutrient fluid.

Now, if the nutrition of the part be augmented, the congestion is due to the greater attraction of the tissues for the blood, the capillaries being first affected by its influence. The nutrition *is* affected, because the blood actually undergoes greater change than on the other side. The capillary circulation, then, in this case, seems clearly to be in a measure dependent on the process of molecular regeneration and disintegration. There is no new action induced in the part, but simply an augmentation of the usual processes; and if this be so, a cause of the capillary circulation is the chemico-vital attraction of the tissues for the blood. The fact that there can be a greater supply of blood, circulating with greater force, on one side of the body than in the corresponding part on the other side, seems to me an insuperable objection to the idea that the heart alone circulates the blood in the capillaries; but I have anticipated, in some degree, the points which I shall hereafter consider more fully.

When I commenced to describe the manner of making observations on the capillary circulation in various parts, I asserted that destruction of the medulla oblongata had no appreciable effect on the capillaries. Brown Séquard has demonstrated, by experiment, that frogs are able to live perfectly well for three or four months after extirpation of the medulla, and that all the functions, except pulmonary respiration, continue to go on apparently as usual.

Before I met with these observations, I made two experiments with reference to the reliability of observations made on a frog after breaking up the medulla or the posterior part of the brain.

In my first experiment, the posterior part of the brain was broken up in an unsuccessful attempt to reach the medulla.

The circulation was observed for seven hours, and was but slightly retarded when the experiment was concluded. For the first two hours, the circulation appeared as usual. I have made numerous unrecorded observations on this point, and have always arrived at the same result, *i. e.*, I have introduced a dissecting needle at the back of the head, sometimes reaching the medulla and sometimes not, but always rendering the frog perfectly quiet and manageable; and I have been unable to discover any effects upon the circulation, or the phenomena produced by irritants.

After making this experiment, I made several dissections so as to be able to reach the medulla oblongata with certainty, and succeeded, in doing so, in making the following observations:—

I examined the circulation for five hours with the same results as in the preceding experiment, *i. e.*, there was no alteration from the appearances of the circulation in the uninjured frog, at least for the first two or three hours.

From these observations, added to my unrecorded experiments, I have no hesitation in asserting that observations on frogs after breaking up the medulla oblongata or the posterior part of the brain, are equally valuable with those made on uninjured frogs; therefore, all the subsequent observations were made after breaking up the medulla, unless otherwise stated.

Dr. Wilson Philip made an experiment which is interesting, though not throwing any light upon the causes of the capillary circulation. "While Dr. Hastings was observing the circulation, he crushed the brain by the blow of a hammer. The vessels of the web instantly lost their power, the circulation ceasing; an effect which we have seen cannot arise from the ceasing of the action of the heart. (Dr. Philip here refers to experiments by which it is ascertained that the blood will circulate for several minutes after the interruption of the heart-action.) In a short time the blood began to move, but with less force." I will here add the notes of a similar experiment performed by myself. The brain of the frog was crushed while Prof. Flint was examining the circulation, which was brisk and regular; the motion instantly ceased, but commenced again in a few seconds, though it proceeded more slowly.

This observation thus in every respect confirms that of Dr. Philip.

This, as I have before remarked, cannot be thought to show that the capillary circulation is dependent upon nervous influence, but merely that a violent shock is able to arrest momentarily all the vital functions. In several of my observations, I have minutely recorded the appearances of the capillary circulation, and have noticed the following phenomena:—

Observation 4th. I examined the web of a young frog.

From a careful and prolonged examination, it is evident that there is a difference between the modes of circulation in the arterioles and the venules. The blood moves more freely in the former, and the motion appears to be dependent on an attractive force—this is not as evident, however, here as in the capillaries; there the blood shoots off to different parts of the tissues in a manner which cannot be dependent upon a "*vis à tergo.*" It also moves much more rapidly in some of the capillaries than in others, the velocity varying in the same vessel at different times. In the venules, the movement is more sluggish, the globules apparently crowding each other along, and, on careful examination, making a decided contrast to the movement in the arterioles. The number of colourless globules is greater in the venules; they adhere to the walls of the vessels, and appear to be pushed along by the central mass, moving very much more slowly, and occasionally remaining stationary for a time.

Obs. 6th. In this observation, the same points attracted attention as in the preceding one, and, in addition, the following phenomena:—

A small transverse capillary, admitting but a single globule at a time, was abruptly bent at a certain point. The globules passed along in single file, irregularly isolated from each other, and were bent nearly double in passing the sudden turn in the vessel. This caused the globules to present a singular appearance at this point; they seemed to move by volition, like animate beings. The motion of the globules, under the above circumstances, is supposed to denote an attractive force.

In several instances the walls of the vessels were distinctly seen; they were perfectly motionless, evidently taking no active part in the circulation. The darting of single globules through small vessels, at a velocity greater than the velocity of the circulation in the vessel from which they branch, was repeatedly remarked.

Obs. 7. The points noticed in Observation 4th were here confirmed. I was forcibly struck with the great difference in the velocity of the circulation in different parts of the field, both in vessels of the same size and of unequal sizes. I also remarked a difference of velocity in the same vessels, especially capillaries, at different times.

An attractive force is evident; a certain condition of the disks is necessary in order that the force should operate. This condition, we may presume, is effected by respiration.

The appearances of the capillary circulation in the web of the foot may be described in the following manner:—

When the web is subjected to examination after the plan already stated, we have vessels of various sizes in the field, consisting of arterioles and venules which vary most in their diameters, and the true capillaries which are all of nearly equal diameters. The blood is seen coursing along the vessels with great rapidity, especially in the arterioles, where we may observe a slight pulsatory movement.

In the arterioles, blood moves with unvarying rapidity as a general rule; and here especially we notice a space next the walls of the vessels, which is not occupied by the red globules, but along which the colourless globules move at a diminished rate, appearing to have a tendency to adhere to the walls of the vessels, and sometimes even remaining entirely stationary for a time, to be pushed along again by the central mass. This constitutes the still layer of Dr. Kirkes.

The white or colourless corpuscles are much fewer than the red, and they move at least ten or twelve times more slowly than the central mass. On careful examination, I have been able to remark a decided difference between the circulation in the arterioles and the venules. In the latter the movement is not so rapid, the globules appearing to be impelled more by a "*vis à tergo,*" and to feel less the "*vis à fronte,*" which seems to operate in the arterioles. The comparative number of the white corpuscles is greater, but the "still layer" appears to occupy a smaller proportion of the calibre of the vessel.

In the true capillaries, the movements are less regular, and apparently dependent in a great measure on a force which acts directly upon them; the "capillary power," as it is designated by Dr. Carpenter. This will be more fully touched upon presently, when we consider the causes of the capillary circulation.

In the true capillaries, the blood moves in every possible direction, at different rates of speed in different vessels, also at different times in the same vessel. In one instance, I remarked a capillary branching from a vessel at an obtuse angle (that is, turning almost directly opposite to the current in the main vessel), and individual globules shooting through it with great rapidity. In many instances, I have observed an entire stasis in one or two of the capillary vessels, but it existed only for a moment, and then recommenced with its original vigour. Dr. Carpenter has remarked a stasis followed by a current in a direction opposite to the original one.

It frequently happens that a globule is caught at the point of junction of two vessels, and remains stationary until it is carried along by the current of blood. Globules are frequently bent upon themselves as they pass from one vessel to another, but as soon as the cause is removed, they regain their original conformation.

The walls of the vessel are motionless, and do not take an active part in the normal circulation, as was supposed by some of the older writers.

Pigment-cells are observed scattered over the field, and when they are very numerous, obscuring the view of the circulation; therefore, it is best to select a light coloured frog for demonstrations.

The pavement variety of epithelium may also be seen.

This is a description of the capillary circulation as it appeared to me under the most favourable circumstances: more minute, but not otherwise differing from the ordinary description in works on Physiology.

We now come naturally to a consideration of the causes of the capillary circulation. I say *causes*, because I shall take the ground that it is not produced by a single cause, namely, the heart's contraction, as was supposed by the great discoverer of the circulation. While it may be that the action of the heart is sufficient to propel the blood through the whole round of the circulation, as is contended by Magendie, by Dr. Allen Thompson, in the *Cyclopedia of Anatomy and Physiology*, Dr. Kirkes, and others, I believe that there are other causes which operate, and are able to carry on the circulation unassisted, as was the case in the acardiac fœtus of Dr. Houston, reported in the *Dublin Medical Journal*, 1837, where, of course, the circulation was stopped at the birth of the child by the want of due aeration of the blood.

Harvey, followed by Magendie, Kirkes, and other eminent physiologists, supposed that the heart was alone concerned in the production of the circulation, and some very striking arguments were made use of to prove it. It is found that, under the most favourable circumstances, a very inconsiderable force is required to propel a bland fluid from the arteries through the capillaries and out again by the veins. The pulsative movements, which we observe under some circumstances in the capillaries, is also brought forward as an argument. Dr. Kirkes dismisses the subject with the remark that "there is no need of an hypothesis of any action of the capillaries for regular propulsion of the blood through them, nor is it probable they have such an office." This appears to me a most unphilosophical mode of treating a very important subject. The circulation of the blood is a process immediately necessary to existence, and even should we agree with him that the action of the heart is capable of carrying on the circulation, it would not be out of place to inquire if there were not some other force which also operates to this end, and could take on, in some degree, the function of circulating the blood, should the heart become weakened from any cause. We know that, in the performance of that essentially vital function, namely, respiration, we commonly use but about one-third of the entire capacity of the lungs, and though the lungs seem to be only aerating organs, they divide that function with the skin. We might as well say that, as the diaphragm is sufficient to carry on respiration, there is no need of supposing that there are any other respiratory muscles. It is the duty of the physiologist to endeavour to ascertain *all* the causes of any of the vital phenomena.

There are several phenomena which are difficult of explanation by the theory of the sole action of the heart in producing the circulation. In the first place, it is difficult to understand how the heart could impel the blood through the second set of the capillaries in the portal system. Then the experiments of Dr. Dowler show that the blood probably circulates in the capillaries, in patients dead from yellow fever, after the heart's action has ceased.

In the frog, Dr. Carpenter asserts, and I have myself seen, that the blood will circulate in the capillaries after complete excision of the heart. Carpenter also mentions instances where the heart has suffered such a degree of fatty degeneration, or replacement, that there existed scarcely a trace of muscular fibre, and the circulation must have been chiefly dependent on the "capillary power." Hassal records a most remarkable phenomenon, namely, the continuance of circulation in a portion of the tongue which had been entirely detached from the organ. He states that, while examining the tongue of a frog, a small portion was torn off, which he placed between two plates of glass, and was astonished to see the circulation continuing in many of the smaller vessels with unabated vigour. This phenomenon he observed for several hours, in connection with several medical gentlemen, and, on examining it the next day, preserving it under water in the mean time, the circulation still continued to some extent. This seems almost incredible, but coming from such authority, the fact cannot be doubted. Hassal appears to have made no subsequent experiments with reference to this point. After seeing this statement, I made two or three experiments, and once saw a slight movement in a portion of the tongue entirely detached; these experiments were not made, however, under favourable circumstances, the weather being cold, and the frog in a state of torpor, until partially aroused by immersion in tepid water.

A case is mentioned by Dr. Carpenter of an acardiac fœtus which was subjected to examination by Dr. Houston, where the organs were tolerably well developed, with the exception of the heart, and the circulation could only be effected by the "capillary power." These cases which I have described, are amply sufficient to disprove the theory that the heart is the sole agent of the circulation. In addition to them, the phenomena of inflammation as seen under the microscope, the normal appearances of the capillary circulation, which appear to the eye to be in some measure dependent on an attraction of the molecules of the tissues for the blood; the experiment of the section of the sympathetic in the neck of the rabbit, which I have previously noticed, and which produced an augmentation of this attractive force in the corresponding ear and side of the face, and comparison with the circulation in some aquatic plants, which we know is not dependent upon the action of a heart, all these go to prove that the heart alone does not produce circulation.

Prof. Draper, of the University of New York, has put forward a theory in regard to the circulation, which makes the heart of minor importance. His is the theory of capillary attraction and affinity. He starts from the proposition that, "if two liquids communicate with each other through a capillary tube, for the substance of which they have affinities of different intensities, movement will ensue; the liquid having the highest affinity will occupy the tube, and may even drive the other from it; the same effect will ensue in a porous object." He believes that this is the great cause of the circulation, namely, an affinity between the blood and the tissues; that thus the blood is forced into the veins, and that the action of the heart is limited to filling the arteries and presenting a supply of blood to the capillaries. The blood circulates in the lungs chiefly from its affinity for oxygen.

This theory cannot be sustained. The heart undoubtedly has a much more important office in the production of circulation. When we cut a small artery, we see the blood forcing itself in a jet to a distance of several feet; and this happens after it had entirely lost the influence of the capillary force. The illustration of Prof. Dunglison, namely, the law that fluids confined in tubes will rise to the same level, and that thus the blood in the veins, by a simple hydrostatic principle, would rise as high as the right auricle in a line with the blood in the left ventricle, shows how slight a force from the heart would be propagated through the capillaries to the veins, and be sufficient to return the blood.

Dr. Dowler, of New Orleans, believes in a distinct capillary action. In some of the experiments which he adduces in support of his position, and which are noticed by Dr. Dunglison in his *Human Physiology*, bodies of yellow fever patients were carried to the dissecting room a few moments after death. "The external veins sometimes became distended, and when punctured, the blood flowed in a good stream; the operation of bleeding at the arm was imitated, and as the muscles were moved, the blood shot forth for some distance." Other experiments on the veins, of a similar character, are recorded by him.

These observations seem to show that there is some action in the capillaries after death, and inferentially during life, which is independent of the heart's action. The entire emptying of the arteries after death cannot be perfectly explained by the mere contraction of the vessels.

What causes seem to operate to produce the capillary circulation, judging merely from the appearances under the microscope? In the observations which I have recorded on this point, we have noted an irregularity of the movement in the capillaries, both in different vessels at the same time, and in the same vessel at different times; the irregularity sometimes amounting to entire cessation of the circulation in a single vessel, and then a current in an opposite direction; a shooting off of single globules through vessels which were before empty, the darting off of globules through capillary branches with a velocity greater than that of the blood in the main vessel; and in short, all the phenomena which are presented to the eye, seem to indicate that there is an attractive force, resident in the solid particles, which operates on the blood in the capillaries.

We are not supposing the existence of a force with the operation of which we are unacquainted. The present school of physiology teaches us that the processes of nutrition, of molecular disintegration, and of secretion, are dependent on a vital force resident in the solid particles of the organism, which are essentially vitalized. Inflammation is now supposed to be due to a perversion of this force.

In what other way could we explain the fact that every tissue takes from the mass of arterial blood the substances which are required for its nutrition. The blood sent to the systemic capillaries by the heart is the same in all parts of the body, but when the great change which is effected in the capillaries has taken place, we find that the blood which has thus been rendered venous is not the same in all the veins; for example, the blood in the renal vein is almost as florid as arterial blood.

The existence of a distinct capillary action is now believed by the highest authorities. Lehmann believes that a chemico-vital attraction of the blood for the tissues, together with the physical capillary attraction, produces the movement of the blood in the capillaries, and forces it into the veins. Dr. Carpenter believes that there exists a "capillary power" which is superadded to the force of the heart. Prof. Dunglison teaches that there is an independent power resident in the tissues about the capillaries, and that, "by the united action of the heart, arteries and capillaries, or intermediate system of vessels, the blood attains the veins." Even those who recognize the heart as the only efficient organ of circulation yield that the capillaries possess a "distributive force;" that is, though the circulation is effected by the heart's unassisted action, that the tissues have an attraction or affinity for the blood, which distributes it for their nutrition to each and every part of the body.

Taking into consideration everything which I have seen bearing on this point, it seems to me to be clearly proved that the normal capillary circulation is dependent, in the first place, on the action of the heart. It cannot be denied that the heart has a considerable share of the duty of capillary circulation. Taking into account the conditions of the blood and vessels, apparently a slight force is capable of propelling the blood through the capillary system. When a small artery is divided, the force with which the blood pumps out is considerable, and appears sufficient to exert a decided effect on the motion of the blood in the capillaries. It is impossible to estimate with much accuracy the proportional influence which the heart has in producing capillary circulation. The vital affinity between the tissues and the blood, which I suppose to be the other power concerned in this function, never ceases; still, as the action of the heart is frequently much interfered with, as in cases of excessive fatty degeneration, and as the heart has been removed from the frog, the capillary circulation nevertheless continuing, we cannot think that its power is greater than the attractive force, or Carpenter's "capillary power," which I hold to be essentially concerned in the performance of this function. The value of the heart's action is also variable, both in different individuals, and in the same individual at different times.

The only other force which has any share in the production of the capillary circulation, unless it be a slight suction force from the veins, is the "capillary power." This seems to me to play the more constant and effective part.

When this ceases to act the animal dies, and the blood refuses to circulate in spite of the heart. This is the great vital force of nutrition which is constantly operating, and which is so wonderful and inexplicable. We know the fact that there is such a force, and that it continually acts, but what it consists of, or what is its essential character, is beyond the wisdom of man to explain. It is life. Lastly, the following inquiry suggests itself: What conditions are necessary to the healthy performance of the capillary circulation?

First, a healthy condition of the vital particles, which is produced by healthy nutrition. Secondly, a particular condition of the blood, which is produced by respiration.

No arguments appear to be necessary to prove the former statement, but I have made experiments, which I shall proceed to describe, which conclusively establish the second point.

The following experiment, made by Dr. J. Reid, and reported in the *Edinburgh Med. and Surg. Journal*, April, 1841, is quoted by Dr. Carpenter:—

Dr. Reid found that when the ingress of air through the trachea of a dog was prevented, and the asphyxia was proceeding to the stage of insensibility, the pressure in the femoral artery, indicated by the hæmadynamometer, was much greater than usual.

Upon applying a similar test to a vein, however, the pressure was proportionally diminished, whence it became apparent that there was an unusual obstruction to the passage of the venous blood (the blood being venous in the arteries) in the systemic capillaries.

Before seeing an account of this experiment, I had made the following observations, carefully recording them, with reference to the same point:—

Obs. 1st. The medulla of a middle sized frog was broken up, and the web submitted to microscopic examination. The frog was bathed with sulphuric ether, care being taken not to allow any to touch the web under examination, and the circulation was watched for ten minutes. No effect could be discovered. The object of this experiment was to determine whether the phenomena in the succeeding experiment were in any degree dependent on the ether which is contained in collodion. The frog was then painted over with an impermeable coating of collodion, care being taken as before not to touch the web. The effect on the circulation was immediate. It instantly became less rapid, until, at the expiration of twenty minutes, it had entirely ceased.

The smaller vessels were the first to become affected, the larger arterioles resisting it longest. One of the first effects was a pulsative movement in vessels where the blood had previously flowed in a continuous stream, showing, as it seems, *that the attractive force is lost, but that the heart's action is felt.* The fact of the first arrest of the blood in the capillaries, seems to indicate that the blood is now unfit to supply wants of the tissues, and that the attractive force ceases to be operative. The arrest of the circulation was steady, and at the expiration of twenty minutes the motion had entirely ceased.

The entire coating of collodion was now instantly peeled off, and the effect on the circulation was instantaneous. Quite a rapid circulation immediately commenced, but it soon began to decline, and in twenty minutes had almost ceased. The heart was now exposed, and found contracting regularly. In this experiment, all respiration was abolished, the medulla being broken up, and an impervious coating applied to the entire surface.

Obs. 2*d.* I painted a frog with a thick coating of collodion, without destroying the medulla. It struggled vigorously at first, but soon became quiet, and the web was put under the microscope.

The circulation was affected in the same manner as in the preceding experiment, and entirely ceased in twenty-five minutes.

During the first few minutes, the nostrils dilated and contracted rapidly, but soon became motionless. Care was taken not to obstruct the nostrils with collodion, though it was applied effectually to all other parts excepting the foot under observation.

The experiment of Dr. Reid proves the fact inferentially, namely, that the blood, deprived of oxygen, as in asphyxia, is retarded in the systemic capillaries; but the experiments just related, bring the processes directly under the eye, and we can see clearly that when the blood is not aerated it will not circulate, though the heart contracts, and that it is retarded in the capillaries. My second experiment demonstrated the comparatively small part which the lungs of the frog take in respiration; the blood circulating in the frog, in which the pulmonary respiration was not interfered with, only five minutes longer than in the frog after destroying the medulla. Capillary circulation will go on in the lungs of the frog after tying the trachea, as I stated when describing the circulation as seen in various parts of the animal, the blood being sufficiently aerated by means of the skin.

Thus it is experimentally proved that an oxygenated state of the blood is an indispensable condition for its circulation through the capillaries. When the process of respiration or aeration of the blood is established, the blood cannot circulate. This we know to be the fact, but we demonstrate, by the preceding experiments, that, in asphyxia, the impediment to the circulation takes place in the capillaries; that the condition of oxygenation is necessary to the performance of the vital functions, and it may be that the entire want of the "capillary power" throws all the onus on the heart, and that the heart is insufficient for the labour. In one of my experiments, after the capillary circulation had entirely ceased, the chest was opened, and the heart found beating regularly.